# Adsorption of Chromium (Vi) from Aqueous Solutions using Low Cost Adsorbent: Equilibrium and Regeneration Studies

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## ABSTRACT

The adsorption of Cr (VI) from aqueous solution by spent tea leaves (STL) was studied at different initial Cr (VI) concentrations, adsorbent dose, pH and contact time under batch isotherm experiments The adsorption experiments were carried out at 30°C and the effects of the four parameters on chromium uptake to establish a mathematical model description percentage removal of Cr (VI). The analysis results showed that the experimental data were adequately fitted to second order polynomial model with correlation coefficients for this model was ($R^2$ = 0.9891). The optimum operating parameters of initial Cr (VI) concentrations, adsorbent dose, pH and contact time were 50 mg/l, 0.7625 g, 3 and 100 min, respectively. At these conditions, the maximum percentage removal of Cr (VI) was 92.88%. The amounts of Cr (VI) adsorbed onto STL were highly affected by the solution pH value. Equilibrium data was modeled with Langmuir and Freundlich models isotherms. Langmuir model is found very well represent the equilibrium data with correlation factor is close to unity than the Freundlich model. The maximum monolayer adsorption capacity was found to be 47.98 mg/g at optimum conditions. The saturated adsorbent was regenerated by base treatment and found to be reuse efficiently after fourth cycle at optimum conditions as well as for safe disposal of base that contains high concentration of Cr (VI) is precipitated as barium chromate.

**KEYWORDS: Adsorption, Removal, Low cost adsorbent, Chromium (VI), Regeneration.**

# أمتزاز الكروم الخماسي من المحاليل المائية بأستخدام مواد مازة واطئة الكلفة : دراسات التوازن وإعادة التنشيط

**الخلاصة:**

تم دراسة أمتزاز الكروم الخماسي من المحاليل المائية بواسطة ورق الشاي المستهلك بتغيير التراكيز الأبتدائية للكروم الخماسي ، كمية المادة المازة ، الدالة الحامضية وزمن التلامس بأستخدام نمط تجارب الوجبات بثبوت درجة الحرارة. تجارب الامتزاز حدثت تحت درجة حرارة 30° م لدراسة تأثير المتغيرات الاربعة على امتزاز الكروم للحصول على موديل رياضي يصف كفاءة ازالة الكروم الخماسي. نتائج التحليل وضحت ان النتائج العملية كانت متطابقة مع معادلة من الدرجة الثانية بمعامل تصحيح مساوياً (0.9891). العوامل التشغيلية المثلى من التراكيز الابتدائية للكروم الخماسي، كمية المادة المازة، الدالة الحامضية وزمن التلامس كانت 50 ملغم/غم، 0.7625 غم، 3 و100 دقيقة، على الترتيب. عند تلك الظروف أعلى نسبة للازالة كانت 92.88% اثبتت بتطابق المحسوب من الموديل الرياضي مع التجارب العملية. كمية الكروم الخماسي الممتز على ورق الشاي المستهلك تأثر بشكل كبير بالدالة الحامضية للمحلول. بيانات الاتزان مثلت مع موديلات متساوية الحرارة (Langmuir) و (Freundlich). موديل (Langmuir) مثل بصورة جيدة بيانات الاتزان مع معامل تصحيح اقترب من الواحد مقارنةً مع موديل (Freundlich) . اعلى نسبة للامتزاز كانت 47.98 ملغم/غم عند الظروف المثلى. تم اعادة تنشيط المادة المازة

المشبعة بمعاملتها مع قاعدة واعادة استخدامها بكفاءة لأربع مراحل عند الظروف المثلى. ولتصريف آمن للقاعدة المحتوية على تراكيز عالية للكروم الخماسي رسب على شكل كرومات الباريوم.

## INTRODUCTION:

The pollution of water resources due to the disposal of heavy metals has been an increasing worldwide concern for the last few decades. Chromium is one of the most toxic heavy metals discharged into the environment through various industrial wastewaters, constituting one of the major causes of environmental pollution. The main industrial sources of chromium pollution are leather tanning, electroplating, metal processing, wood preservatives, paints and pigments, textile, dyeing, steel fabrication and canning industry (Singh *et al.*, 2009). The most common forms of chromium are trivalent chromium [Cr (III)] and hexavalent chromium [Cr (VI)]. Hexavalent chromium forms chromate ($CrO_4^{-2}$) or hydrogen chromate ($HCrO_4^{-}$) that is more toxic and more soluble. The exposure of Cr (VI) to human causes nausea, diarrhea, liver and kidney damage, dermatitis, internal hemorrhage and respiratory problems. The maximum concentration limit for chromium (VI) for drinking water is 0.05 - 0.1 mg/L (Surendra and Dharmendra, 2012).

There are various treatment technologies available to remove Cr (VI) from wastewater such as chemical precipitation (Uysal and Irfan, 2007), ion-exchange (Jianlong and Xinmin, 2000), membrane separation (Kozlowski and Walkowiak, 2002), electrocoagulation (Roundhill and Koch, 2002), solvent extraction (Li *et al.*, 2004), and adsorption (Baral *et al.*, 2007) and (Mohan *et al.*, 2005). These techniques are economically expensive for the removal of Cr (VI) from wastewater. The above mentioned removal techniques have many disadvantages such as incomplete metal removal, high reagent and energy requirements, and generation of toxic sludge or waste products which require proper disposal without creating any problem to the environment (Aliabadi *et al.*, 2006) and (Mohan and Pittman, 2006). Therefore, there is a dire need of a treatment method for Cr (VI) removal from wastewater which is simple, effective and inexpensive (Babu and Gupta, 2008).

Because of high performance and ease of use, adsorption is introduced as one of the most applied methods (Bailey *et al.*, 1999). In this method heavy metals are adsorbed in the pore surface of adsorbent which is insoluble in water. One of the most common adsorbent for heavy metals is activated carbon, which because of its high cost of activating processes is very expensive. In recent years cheap adsorbents have been attractive to many of researchers. Cheap adsorbents are widely and easily in reach and their preparation cost is low. These adsorbents are mainly a waste result of industrial and agricultural activity and have cellulose base (Hassan *et al.*, 2012). Adsorption technology is easy to use, no need for processing and complex reforming processes, efficient and selective for heavy metals.

The objective of the present study is to investigate the possible use of STL as a cheap adsorbent material for the removal of Cr (VI) from wastewater. Batch experiments are carried out for studies the removal of Cr (VI) from aqueous solution. The influence of various important parameters such as initial Cr (VI) concentration, adsorbent amount, pH, and contact time are investigated. The Langmuir and Freundlich models are used to fit the experimental equilibrium isotherm data obtained in this study.

## MATERIALS AND METHODS:

### Materials

The adsorbent STL was collected from the local sources. The tea leaves was washed several times in distillate water to remove any adhering dirt and repeatedly boiled with water until the filtered water was cleared. Then it was oven dried at 80 $^{o}$C for 24 h. Finally, the dried sample was ground and sieved to obtain a particle size range of 3–6 mm and stored in plastic bottle for further use.

## Chemicals

All the chemicals used are of analytical grade. A stock solution of 1000 mg/l of Cr (VI) is prepared by dissolving 2.8287 g of 99.9% potassium dichromate ($K_2Cr_2O_7$) in 1000 ml of solution. This solution is diluted as required to obtain the standard solutions containing (50-500) mg/l of Cr (VI). The concentration of Cr (VI) ions in the effluent is determined spectrophotometrically by developing a purple violet color with 1,5-diphenyl carbazide in acidic medium by following APHA, AWWA standard methods for examination of water and wastewater (APHA, AWWA, 1998). The absorbance of the purple-violet colored solution is read at 540 nm after 20 min. pH adjustment is carried out by using 0.5N HCl and 0.5N NaOH solutions.

## Batch Experiments

The adsorption experiments were carried out in isothermal batch process at 30°C ± 1°C and the effect of different parameters such as initial Cr (VI) concentration, adsorbent dose, pH and contact time were studied. The experiments were conducted by adding an amount of adsorbent varied between (0.05-1) g with 100 ml of Cr (VI) solution of different initial concentration (50-500) mg/l in 250 ml stopper conical flasks. These flasks were placed on a rotating shaker with constant shaking at 150 rpm to maintain the equilibrium condition. The range of experimental variables could be represented in the **Table 1**.

**Table 1** Range of Experimental Variables

| **Initial Conc. of Cr(VI) (mg/l)** | **Adsorbent Dose (g)** | **pH** | **Contact Time (min)** |
|---|---|---|---|
| 50 - 500 | 0.05 - 1 | 1 - 9 | 20 - 180 |

At different intervals of time, samples were drawn out of the adsorber using syringe (2ml). Cr (VI) concentration was measured using a spectrophotometer in the visible range at maximum wave length. The percentage of removal efficiency (% R) for Cr (VI) was calculated according to the following equation:

$$\% \ R = \frac{C_o - C_e}{C_o} \times 100 \qquad (1)$$

Also, the amount of adsorption at equilibrium, qe (mg/g), was calculated by:

$$q_e = \frac{V\ (C_o - C_e)}{W} \qquad (2)$$

where $C_o$ and $C_e$ (mg/l) are the concentrations of Cr (VI) at initial and equilibrium, respectively. V (L) is the volume of the solution and W (g) is the mass of dry sorbent used.

## Statistical Design of Experiments:

Box-Wilson experimental design method, commonly called "Central Composite Design", was used to establish a mathematical model relating the removal efficiency (Y) of Cr (VI) with various operating variables such as initial Cr(VI) concentration ($X_1$), adsorbent dosage ($X_2$), pH ($X_3$) and contact time ($X_4$) (Box and Hunter, 1957). The relationship between coded level and corresponding real variables were tabulated in **Table 2**.

The needed number of experiments (N) depends on number of variable (q) and was estimated according to the following equation (Montogomery, 1984):

$$N = 2^q + 2q + 1 \qquad (3)$$

In accordance with eq.(3), twenty-nine experiment were carried out with four operating conditions. Also, the form of a quadratic (second order model) polynomial is illustrated by the following equation (Montogomery, 1984):

$$Y = A_o + A_1X_1 + A_2X_2 + A_3X_3 + A_4X4 + A_5X_1^2 + A_6X_2^2 + A_7X_3^2 + A_8X_4^2 + A_9X_1X_2 + A_{10}X_1X_3 + A_{11}X_1X_4 + A_{12}X_2X_3 + A_{13}X_2X_4 + A_{14}X_3X_4 \qquad (4)$$

where Y is the predicted response, X is the coded value of the independent variable and A is a coefficient. At the present study, the central composite design was used for optimization of the adsorption process and to evaluate the effects and interactions of the process variables. The experimental data was analyzed by using Statistics–Software program version 7. It was made under "non-linear estimation". The obtained equation was verified by applying the F–test and analyzing the correlation coefficients (R) and variance explained (S) by comparison between the calculated and experimental values. To evaluate the optimum conditions that give the maximum response (highest removal efficiency) were determined using analysis by a central composite experimental to get desirability operating variables (Zivorad, 2004).

**Table 2** The Relationship Between Coded Level and Corresponding Real Variables

| Coded Level | Initial Conc. of Cr (VI) (mg/l) | Adsorb-ent Dose (g) | pH value | Contact Time (min) |
|---|---|---|---|---|
| -2 | 50 | 0.05 | 1 | 20 |
| -1 | 162.5 | 0.2875 | 3 | 60 |
| 0 | 275 | 0.525 | 5 | 100 |
| 1 | 387.5 | 0.7625 | 7 | 140 |
| 2 | 500 | 1 | 9 | 180 |

## Analysis of Experimental Results:

The response of experimental work conducted according to Box-Wilson design is represented by the mathematical model that described the removal efficiency (Y) of Cr (VI) from aqueous solution on STL which gave:

$$Y = 45.3513 + 0.005348\ X_1 + 86.35611\ X_2 - 0.3463\ X_3 + 0.27418\ X_4 - 0.00009\ X_1^2 - 40.1108\ X_2^2 - 0.159375\ X_3^2 - 0.000789\ X_4^2 + 0.018713X_1X_2 + 0.005556X_1X_3 - 0.000306\ X_1X_4 - 3.42105X_2X_3 - 0.105263X_2X_4 + 0.0125\ X_3X_4 \qquad (5)$$

[illegible] insignificant. Thus, the best form of the equation representing the removal efficiency can be written as follows:

$$Y = 45.3513 + 0.005348\ X_1 + 86.35611\ X_2 - 0.3463\ X_3 + 0.27418\ X_4 - 0.00009\ X_1^2 - 40.1108\ X_2^2 - 0.159375\ X_3^2 - 0.000789\ X_4^2 + 0.005556\ X_1X_3 - 0.000306\ X_1X_4 - 3.42105\ X_2X_3 - 0.105263X_2X_4 + 0.0125X_3X_4 \qquad (6)$$

Correlation coefficient ($R^2$) = 0.9891
Variance Explained (S) = 97.839 %

The optimum conditions for the four factors that give maximum adsorption capacity are:
$X_1^*$: optimum initial Cr (VI) concentration = 50 mg/l
$X_2^*$: optimum amount of adsorbent dose = 0.7625 g
$X_3^*$: optimum pH solution value = 3
$X_4^*$: optimum time contact = 100 min
$Y_{max.}$: max. removal percentage = 92.88 %

## RESULTS AND DISCUSSION:

Batch experiment were carried out to investigate the effects of initial Cr (VI) concentration, adsorbent dose, pH and contact time on percent removal of Cr (VI) from aqueous solution.

### Effect of Initial Cr (VI) Concentration

**Fig.1** shows the effect of Initial Cr (VI) concentration on the removal of Cr (VI) for different amount of adsorbent dose (0.05-1) g and at constant optimum value of pH and contact time, 3 and 100 min, respectively. The result indicated that the percentage of Cr (VI) removal increases with increasing the adsorbent dose. The high sorption at the initial concentration may be due to an increased number of vacant sites on the adsorbent available at the initial stage. As concentration of initial Cr (VI) is increased there is a decrease in percentage removal of Cr (VI). This can be attributed to the accumulation of Cr (VI) particles on the surface of adsorbent. This observation is in a good agreement with the findings of Gupta and Babu (2009) on sawdust and Singh *et al.* (2009) on wheat bran.

**Fig.2** shows the same effect but for different pH value and optimum conditions of adsorbent dose (0.7625 g), optimum contact time (100 min). Also, it can be seen that the percent of removal is favored at pH value near 3.

**Fig.3** shows the same effect but for different contact time and optimum conditions of adsorbent dose (0.7625 g) and pH value (3). The results showed that more than 90% of the Cr (VI) was adsorbed within a period of 80 min. The maximum uptake of Cr (VI) was (47.98 mg/g) observed within 100 min.

## Effect of Adsorbent Dosage

**Fig.4** shows the effect of adsorbent dose on the removal of Cr (VI) for different initial Cr (VI) concentrations (50-500) mg/l and at constant optimum pH value of 3 and constant optimum contact time of 100 min. The result showed that the percentage removal of Cr (VI) increases with the increase in adsorbent dosage till optimal amount of adsorbent (0.7625 g), after this, the removal of Cr (VI) curves are smooth and continues leading to saturation. This can be attributed to increased adsorbent surface area and availability of more adsorption sites resulting from the increasing adsorbent dosage. This result agrees with the finding of most researchers such as Mohammad *et al.* (2011) and Hassan *et al.* (2012).

**Fig.5** shows the same effect but for different pH value and optimum conditions of initial of Cr (VI) concentration (50) mg/l and optimum contact time (100 min). The result showed that the percentage of Cr (VI) removal increases with increasing the adsorbent dose.

**Fig.6** shows the same effect but for different contact times and optimum conditions of initial Cr (VI) concentration (50) mg/l and optimum pH value (3). It can be, also, seen that increasing the contact time shall increase the percentage removal of Cr (VI). Similar results were obtained by Cimino *et al.* (2000) and Ali (2010). The results also clearly indicated that the removal efficiency increases up to the optimum dosage beyond which the removal efficiency is negligible.

## Effect of pH Value

The pH of the solution is an important parameter in the adsorption process because it affects the solubility of the metal ions concentration of the counter ions on the functional groups of the adsorbent (Surendra and Dharmendra, 2012). The effect of pH value on the percentage removal of Cr (VI) at optimum values of the others factor is shown in **Figs. 7,8 and 9**. From these figures it can be shown that the percentage removal of Cr (VI) decrease with increasing the pH value from 3 to 9. Chromium exists mostly in two oxidation states which are Cr (VI) and Cr (III) and the stability of these forms is dependent on the pH of the system (Cimino *et al.*, 2000). It is well known that the dominant form of Cr (VI) at aforesaid pH is $HCrO_4^-$ which arises from the hydrolysis reaction of the dichromate ion ($Cr_2O_7^{-2}$) according to the equation:

$$2HCrO_4^- + H^+ \longrightarrow 2H_2CrO_4 \qquad (7)$$

$$2H_2CrO_4 \longrightarrow Cr_2O_7^{-2} + 2H_2O \qquad (8)$$

Increasing the pH will shift the concentration of $HCrO_4^-$ to $Cr_2O_7^{-2}$. Maximum adsorption at pH range 1 to 3 indicates that it was the $HCrO_4^-$ form of Cr (VI), which was the predominant species at this pH range and adsorbed preferentially on the adsorbents. Better adsorption capacity observed at low pH values with desired range of pH between 1 and 3 may be attributed to the large number of $H^+$ ions present at these pH values, which in turn neutralize the negatively charged hydroxyl group (−OH) on adsorbed surface thereby reducing the hindrance to the diffusion of dichromate ions. At higher pH values, the reduction in adsorption may be possible due to abundance of $OH^-$ ions causing increased hindrance to diffusion of dichromate ions. Similar results were obtained by Bhattacharya *et al.* (2008) and Surendra and Dharmendra (2012).

## Effect of Contact Time:

The effect of contact time on the percentage removal of Cr (VI) at optimum conditions of the other factors is the presented in **Figs. 10,11 and 12**. These figures show that the removal of Cr (VI) increases with increasing mixing contact time attains equilibrium in 100 min that equilibrium time was independent of initial Cr (VI) concentration. . After this period the removal curves are single smooth and continuous, suggesting the formation of monolayer of adsorbate on the surface of the adsorbent. These results indicated that the sorption process can be considered very fast because of the large amount of Cr (VI) attached to the sorbent within the first 60 min of adsorption. The higher sorption rate at initial period can be attributed to the increase of number of vacant site on the adsorbent available at the initial stage. This result of equilibrium time is in agreement with those obtained by Surendra and Dharmendra (2012) on Spirogyra algae and Singh *et al.* (2009) on wheat bran were attained equilibrium time at 100 and 110 min, respectively.

## ADSORPTION ISOTHERMS:

The experimental data are analyzed by the Langmuir and Freundlich equilibrium adsorption isotherm. The Langmuir isotherm was represented by the following equation (Davis *et al.*, 2003):

$$\frac{1}{q_e} = \frac{1}{q_o} + \frac{1}{q_o K_l} \cdot \frac{1}{C_e} \qquad (9)$$

The linear plots of $1/q_e$ versus $1/C_e$ suggest the applicability of the Langmuir isotherms **Fig.13**. The values of $q_o$ and $K_l$ were determined from slope and intercepts of the plots and are presented in **Table 3**. The Langmuir constants $q_o$ and $K_l$ are related to the adsorption capacity (amount of adsorb ate adsorbed per unit mass of the adsorbent to complete monolayer coverage) and energy of adsorption, respectively. The highest value of adsorption capacity $q_o$ (maximum uptake) was (47.98 mg/g). To confirm the favorability of the adsorption process, the essential characteristics of the Langmuir isotherm may be expressed in terms of a dimensionless constant separation factor or equilibrium parameter (Weber and Chakraborti, 1974), $R_L$, which is defined as:

$$R_L = \frac{1}{1 + K_l C_o} \qquad (10)$$

where $C_o$ is the initial concentration (mg/l) and $K_L$ is the Langmuir constant related to the energy of adsorption (l/mg). The value of $R_L$ indicates the shape of the isotherms to be either unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$) or irreversible ($R_L = 0$) (McKay *et al.*, 1982). The calculated $R_L$ values at different initial Cr (VI) concentration which is found in the range of 0.3945 and 0.06118 ($0 < R_L < 1$) which confirms the favorable adsorption process for Cr (VI) removal using STL. The calculated $R_L$ values are shown in **Fig.14**. Also, higher $R_L$ values at lower ion concentrations showed that adsorption was more favorable at lower concentration.

The Freundlich equation is an empirical equation employed to describe heterogeneous systems, in which it is characterized by the heterogeneity factor 1/n and is as the following (Freundlich, 1906):

$$q_e = K_f \cdot C_e^{1/n} \qquad (11)$$

where $K_f$ and $n$ are the Freundlich constants that indicate the adsorption capacity and intensity, respectively. The linear form of Freundlich model can be written as:

$$\ln q_e = \ln K_f + \frac{1}{n} \ln C_e \qquad (12)$$

The values of $K_f$ and $n$ are evaluated from both intercept and slope, respectively, of the linear plot of the experimental data of $\ln q_e$ versus $\ln C_e$ as illustrated in **Fig. 15**.The values of $K_f$ and $n$ given in the **Table 3** show that the increase in negative charges on the adsorbent surface makes electrostatic forces between the adsorbent surface and Cr (VI) ion.

**Table 3** Parameters of Langmuir and Freundlich isotherm models

| **Langmuir Constants** | | |
|---|---|---|
| $q_o$ (mg/g) | $K_l$ (l/mg) | $R^2$ |
| 62.1041 | 0.03068 | 0.99978 |
| **Freundlich Constants** | | |
| $K_f$ (mg/g)/(mg/l)$^{1/n}$ | 1/n | $R^2$ |
| 3.5629 | 0.5702 | 0.97473 |

In general, $R^2$ values, which are a measure and describe of goodness fit adsorption data with Langmuir and Freundlich isotherm models. From **Table 3**, it can be seen that the values of correlation factor $R^2$ is close to unity for Langmuir model which indicates that the experimental results on adsorption were fitted very well to the Langmuir adsorption isotherms than the Freundlich model.

**Fig.16** shows the maximum adsorption capacity at different Cr (IV) concentration and optimum other factors.

## REGENERATION STUDIES:

The saturated adsorbent which contains Cr (VI) is not safe for the disposal due to the stringent environmental constraints. It is important and appropriate to propose a method for the regeneration and reuse of adsorbent so as to reduce the load on environment in terms of disposal of polluted adsorbent as well as reduction cost of adsorption process. In the present study, after the optimized conditions for the removal of Cr (VI) were determined, STL was recovered by filtration and regenerated using 2N NaOH then washed by deionized water until the pH of the wash effluent stabilized near 7. Finally, it was dried in oven at 80 $^{o}$C for 24 hr for reuse it to the removal of Cr (VI) at optimum conditions for initial Cr (VI) concentration, adsorbent dose, pH and contact time were 50 mg/l, 0.7625 g, 3 and 100 min respectively. **Fig.17** shows the percentage removal of Cr (VI) using regenerated STL. The percentage removal of Cr (VI) obtained found decrease from 88.3 % to 71.8 % after fourth regeneration cycle. The regenerated STL can be recycled effectively for the adsorption of Cr (VI) which makes the process cost effective.

The major problem of adsorption process is the disposal of the base solution obtained which contains high concentration of Cr (VI). One of the methods to tackle this problem is precipitation of Cr (VI) from the aqueous solution using barium chloride. Addition of barium chloride solution to Cr (VI) solution precipitates a bright yellow barium chromate, as given by the following reaction:

$$Ba_2{}^{+}{}_{(aq)} + CrO_4{}^{-2}{}_{(aq)} \longrightarrow BaCrO_{4(s)} \qquad (13)$$

The precipitated solid volume is very less as compared to the volume of the solution. Also, the chromium present in the complex solid can be recovered and reused by the industries. So this way the problem of disposal which is a major disadvantage of adsorption operation can be solved effectively and efficiently.

## CONCLUSION:

The present work shows that STL is an efficient and more costly adsorbent for the removal of Cr (VI) from aqueous solution. The response surface methodology based on Box-Wilson design was used to develop mathematical model for predicting Cr (VI) removal by STL and employed to determine the optimal process parameters such as initial Cr (VI) concentration, STL dosage, pH and mixing contact time on the adsorption of Cr (VI) were obtain 50 mg/l, 0.7625 g, 3 and 100 min, respectively, the maximum percentage removal of Cr (VI) was 92.88% at optimum conditions. Analysis of variance showed a high correlation coefficient of determination value ($R^2$= 0.9891), thus ensuring a satisfactory adjustment of the second order regression model with the experimental data. The results show that the adsorption of Cr (VI) onto the STL is highly pH dependent. Hence, adsorption of Cr (VI) is accomplished by increasing the pH value. The equilibrium adsorption data are tested with Langmuir and

Freundlich isotherm models. The equilibrium data are best fitted with Langmuir than Freundlich isotherm model. The maximum adsorption capacity was 47.98 mg/g. The essential factor $R_L$ revealed the favorability of STL on Cr (VI) adsorption. The saturated adsorbent was regenerated by base treatment and can be reuse after four times with high efficient. The disposal of the base solution obtained that contains high concentration of Cr (VI) is the precipitation of Chromium as barium chromate.

## REFERENCES:

- Aliabadi M., Morshedzadeh K. and Soheyli H., (2006), "**Removal of Hexavalent Chromium from Aqueous Solution by Lignocellulosic Solid Wastes**", Int. J. Environ. Sci. Technol. 3, pp. 321–325.
- APHA, (1998), **Standard Methods for the Examination of Water and Wastewater**, 20th ed., APHA, AWWA, WPCF, Washington D.C., New York.
- Bailey. S., Olin T., Bricka R. and Adrian D., (1999), "**A review of Potentially Low Cost Sorbents for Heavy Metals**", Water Research, 33, pp. 2469-2479.
- Baral S., Das S., Rath P. and Chaudhury R., (2007),"**Chromium (VI) Removal by Calcined Bauxite**", Biochem. Eng. J., 34, pp. 69–75.
- Babu B. and Gupta S., (2008), "**Adsorption of Cr (VI) Using Activated Neem Leaves as an Adsorbent: Kinetic Studies**", Adsorption, 14, pp. 85–92.
- Box, G. E. and Hunter, J. C., (1957), "**Multifactor Experimental Design for Exploring Response Surface**", Ann. Math, vol.28, p.195.
- Bhattacharya A., Naiya T., Mandal S. and Das S., (2008), "**Adsorption, Kinetics and Equilibrium Studies on Removal of Cr(VI) from Aqueous Solutions Using Different Low Cost Adsorbents**", Chemical Engineering Journal, 137, pp. 529–541.
- Cimino G., Passerini A. and Toscano G., (2000), "**Removal of Toxic Cations and Cr(VI) from Aqueous Solution by Hazelnut Shell**", Water Res. 34, pp. 2955–2962.
- Davis, T.A., Volesky, B., Mucci, A., (2003), " **A review of the Biochemistry of Heavy Metal Biosorption by Brown Algae**", Wat. Res. 37, pp. 4311-4330.
- Freundlich H., (1906), "**Adsorption in Solution**", Phys.Chem. Soc., 40, pp. 1361–1368.
- Gupta S. and Babu B., (2009), "**Removal of Toxic Metal Cr(VI) from Aqueous Solutions Using Sawdust as Adsorbent**", Chemical Engineering Journal, 150, pp. 352-365.
- Hassan M., Samaneh A. and Morteza B., (2012), "**Removal of Chromium (VI) and Cadmium from Aqueous Solution Using Orange Peel as A Cheap Sorbent**", Journal of Applied Sciences in Environmental Sanitation Vol. 7, 4, pp. 269-273.
- Jianlong W., Xinmin Z. and Yi Q., (2002), "**Removal of Cr (VI) from Aqueous Solution by Macroporous Resin Adsorption**", J. Environ. Sci. Health A 35, 1211–1230, **2000**.
- Kozlowski C. and Walkowiak W., (2002),"**Removal of Chromium (VI) from Aqueous Solutions by Polymer Inclusion Membranes**", Water Res., 36, pp. 4870–4876.
- Li C., Chen H. and Li Z., (2004),"**Adsorptive Removal of Cr(VI) by Fe-Modified Steam Exploded Wheat Straw**", Proc. Biochem., 39, pp. 541–545.
- Mohan D., Singh K. and Singh V., (**2005**), "**Removal of Hexavalent**

**Chromium from Aqueous Solution Using Low Cost Activated Carbons Derived from Agricultural Waste Materials and Activated Carbon Fabric Cloth**", Ind. Eng. Chem. Res., 44, pp. 1027–1042.

- Mohan D. and Pittman C., (2006), "**Activated Carbons and Low Cost Adsorbents for Remediation of Trivalent and Hexavalent Chromium from Water**", J. Hazard. Mater, B137, pp. 762–811.

- Montogomery, D.G., (1984), "**Design and Analysis of Experiments**", 2nd ed., John Wiley.

- Mohammad R., Mina S. and Pourya B., (2011), "**Removal of Cr (VI) from Aqueous solution Using Pine Needles Powder as Adsorbent**", Journal of Applied Sciences in Environmental Sanitation, vol. 6, No. 1, pp. 1-13.

- McKay, G., Blair, H. and Gardener J., (1982), "**Adsorption of Dyes on Chitin. I. Equilibrium Studies**", J. Appl. Polym. Sci., 27, pp. 3043 – 3057.

- Roundhill D. and Koch H., (2002), "**Methods and Techniques for the Selective Extraction and Recovery of Oxo-Anions**", Chem. Soc. Rev., 31, pp. 60–67.

- Singh K., Hasan S., Talat M, Singh V. and Gangwar S., (2009), "**Removal of Cr (VI) from aqueous solutions using wheat bran**", Chemical Engineering Journal, 151,113–121.

- Surendra B. and Dharmendra S., (2012), "**Adsorption of Cr (VI) Metal Ion from Aqueous Solutions on Low Cost Adsorbent**", Journal Biointerface Research in Applied Chemistry, vol. 2, 2, pp. 284-290.

- Uysal M. and Irfan A., (2007), "**Removal of Cr (VI) from Industrial Wastewaters by Adsorption**", Part I: Determination of optimum Condition, J. Hazard Mater, 149, pp. 482–491.

- Weber T. and Chakraborti R., (1974), "**Pore and Solid Diffusion Models for Fixed Bed Adsorbents**", AIChE J., 20, pp. 228–238.

- Zivorad R., (2004), "**Design of Experiments in Chemical Engineering**", Wiley-VCH, ISBN: 3.527.31142.4.

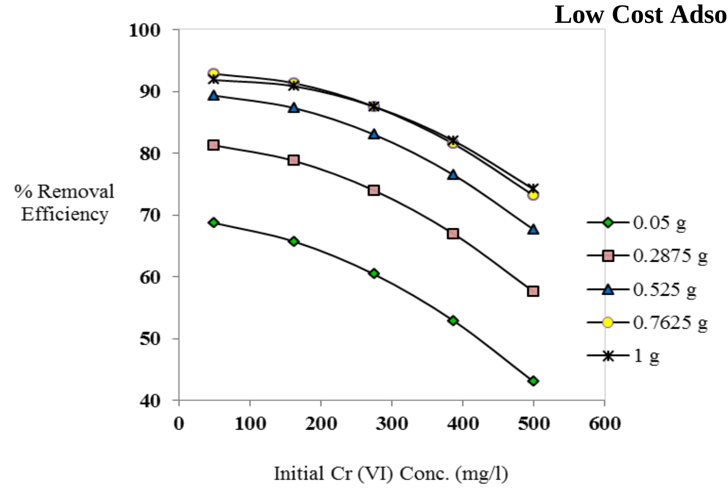

**Fig. 1** Effect of initial Cr (VI) concentration on removal efficiency at different adsorbent doses

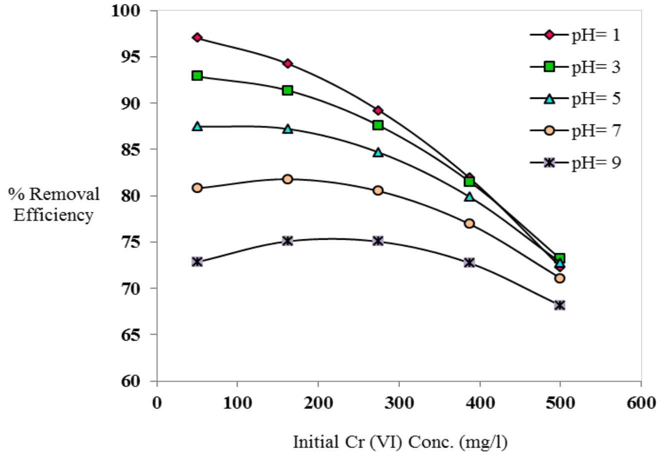

**Fig. 2** Effect of initial Cr (VI) concentration on removal efficiency at different pH

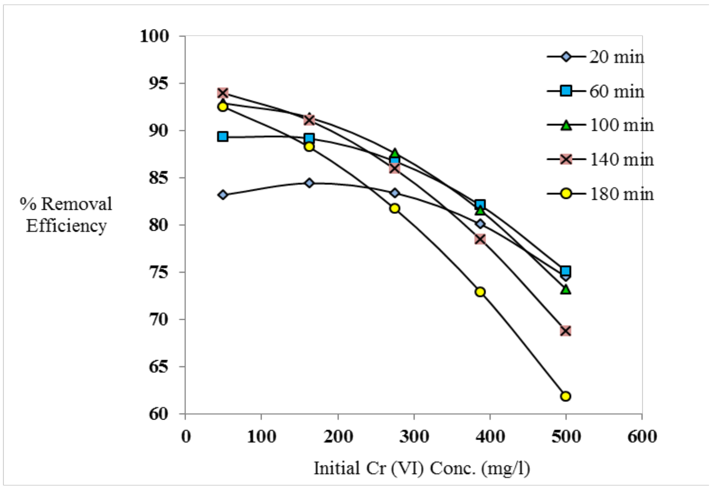

**Fig. 3** Effect of initial Cr (VI) concentration on removal efficiency at different contact time

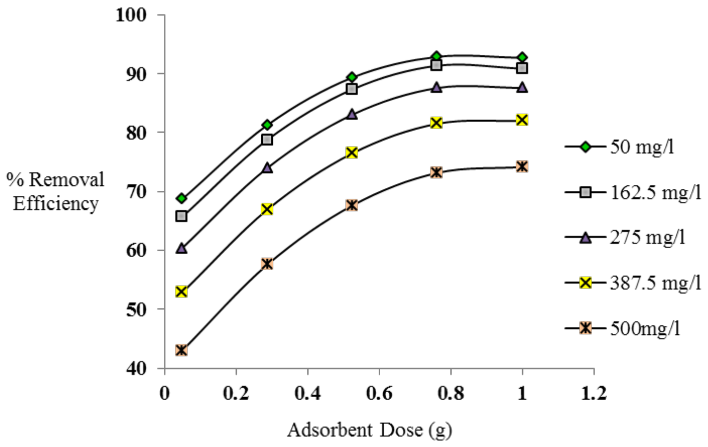

**Fig. 4** Effect of adsorbent dose on removal efficiency at different initial Cr (VI) concentration

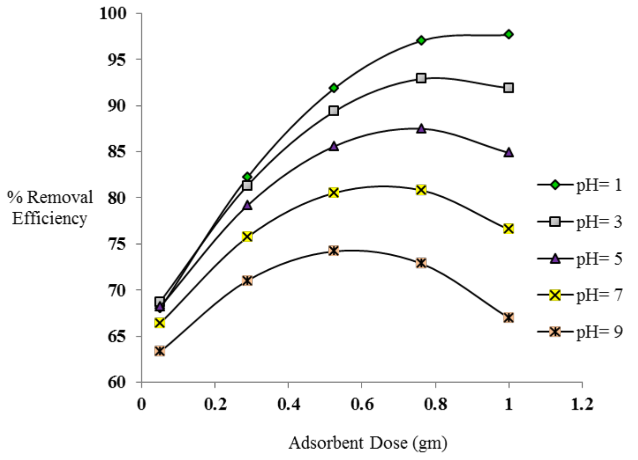

**Fig. 5** Effect of adsorbent dose on removal efficiency at different pH

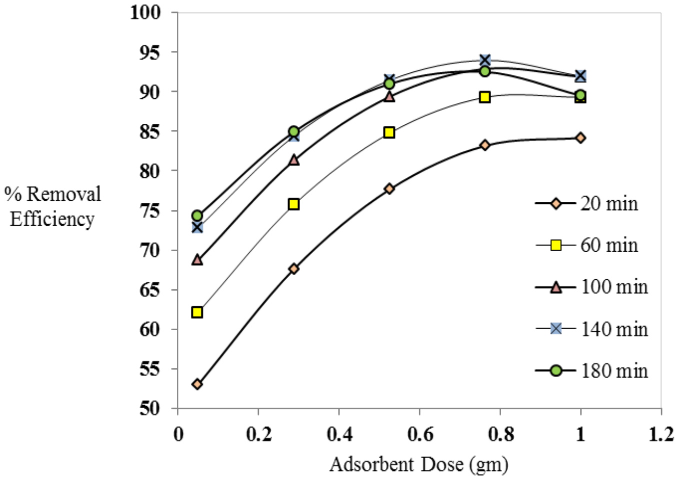

**Fig. 6** Effect of adsorbent dose on removal efficiency at different contact time

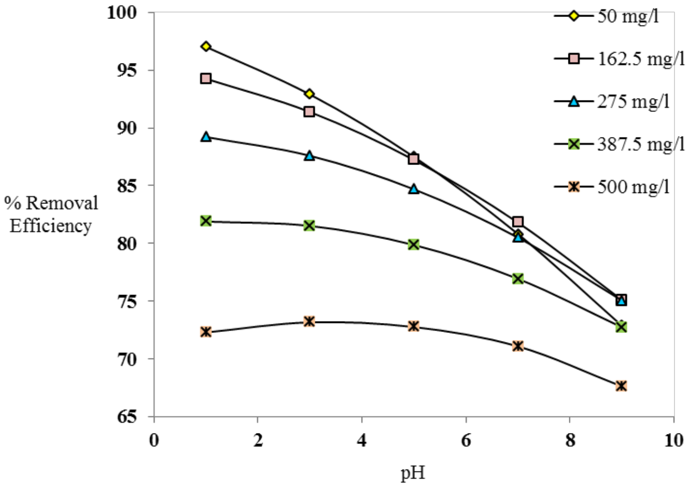

**Fig. 7** Effect of pH on removal efficiency at different initial Cr (VI) concentration

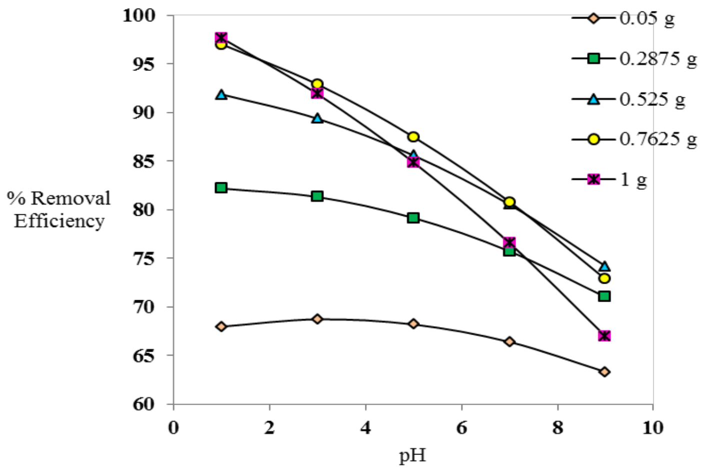

**Fig. 8** Effect of pH on removal efficiency at different adsorbent dose

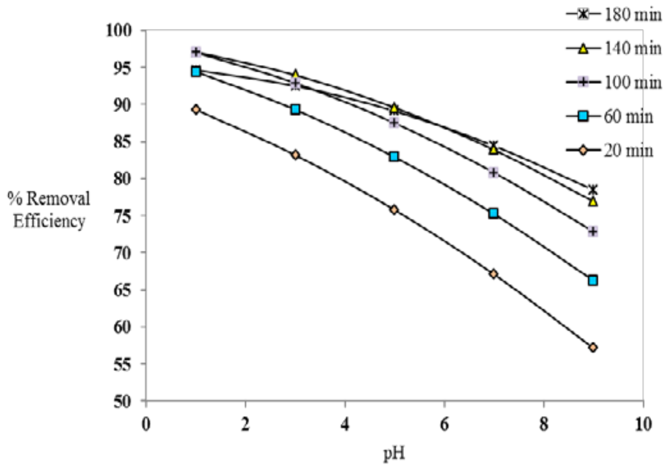

**Fig. 9** Effect of pH on removal efficiency at different contact time

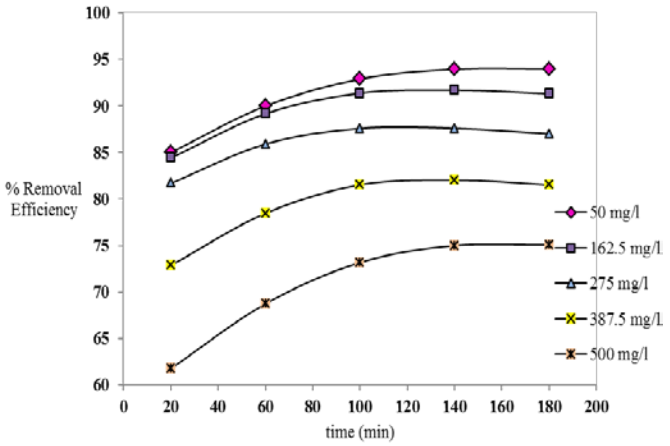

**Fig. 10** Effect of contact time on removal efficiency at different initial Cr (VI) concentration

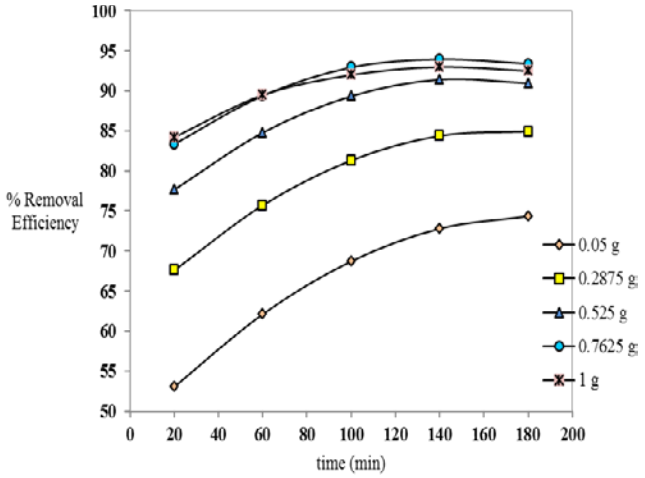

**Fig. 11** Effect of contact time on removal efficiency at different adsorbent dose

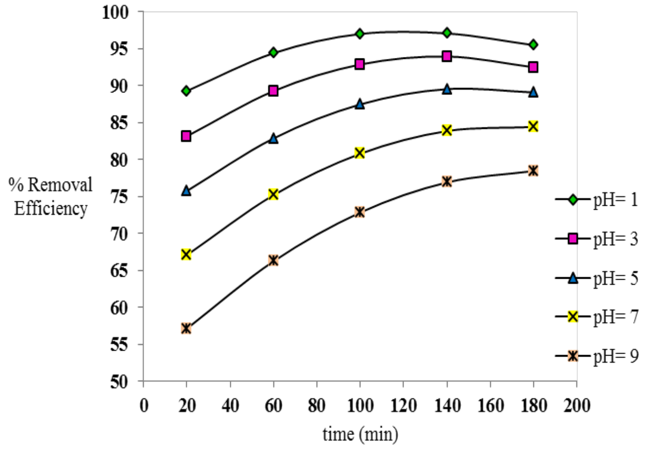

**Fig. 12** Effect of contact time on removal efficiency at different pH

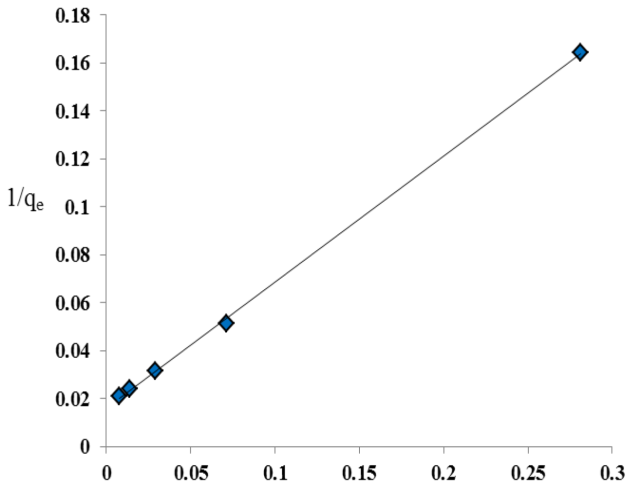

**Fig. 13** Langmuir isotherm for Cr (VI) adsorption on STL

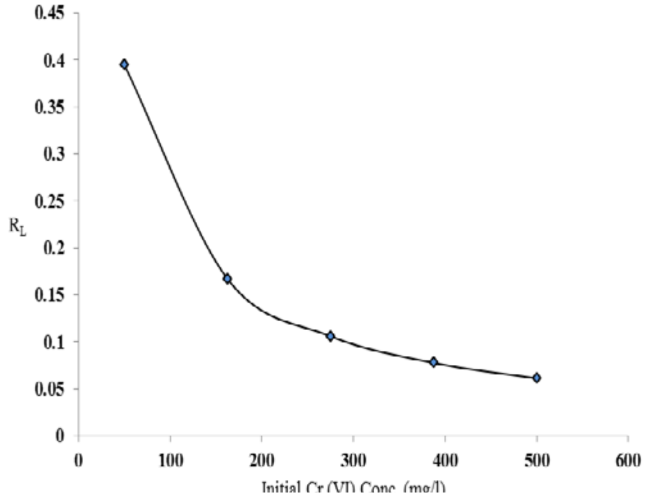

**Fig 14** The Separation Factor for Cr (VI)

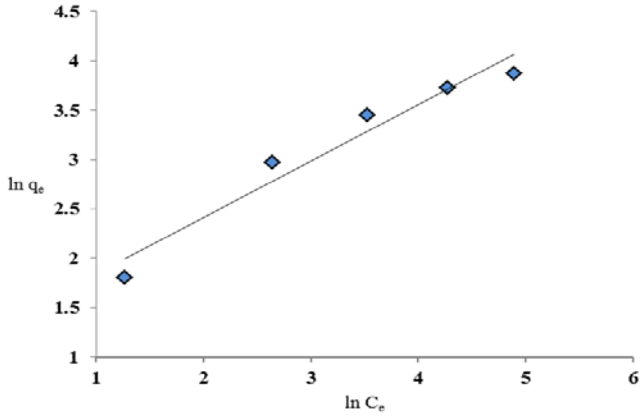

**Fig. 15** Freundlich isotherm for Cr (VI) adsorption on STL

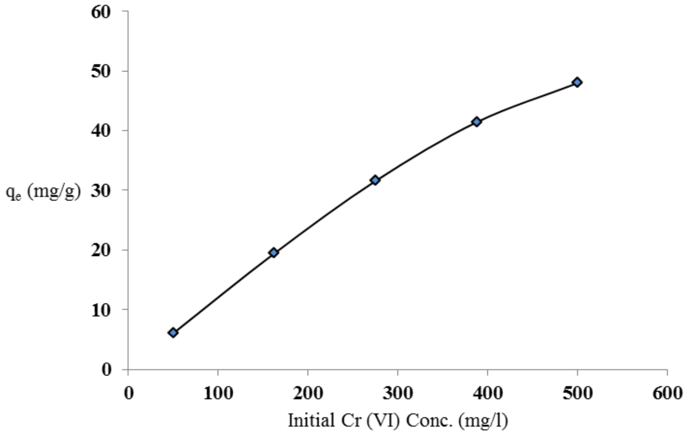

**Fig. 16** Maximum uptake for Cr (VI) adsorption on STL at optimum conditions

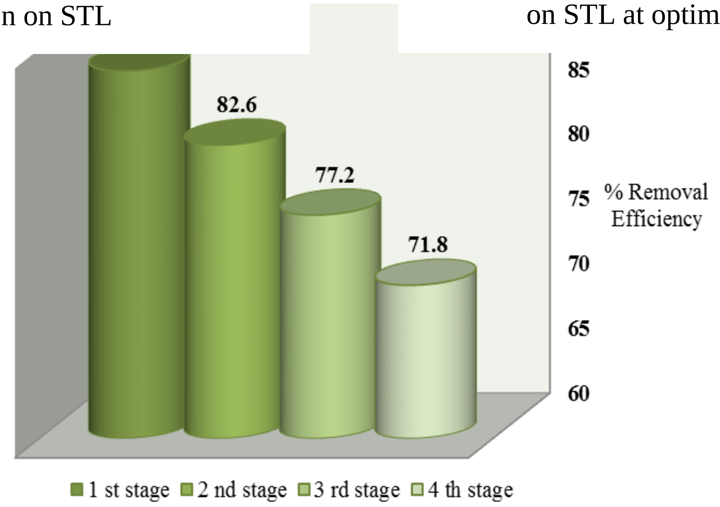

**Fig. 17** Regeneration STL adsorbent at optimum conditions